# Biological and Cultural Plant Disease Controls: Alternatives and Supplements to Chemicals in IPM Systems

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Biological and cultural controls are two alternatives to synthetic chemical pesticides in integrated pest management systems. However, pesticides will continue to be required in many production systems if quality and competitiveness are to be maintained by producers. Therefore, within the foreseeable future, biological and cultural controls will be utilized in integrated management systems both as alternatives and supplements to pesticides.

Several factors are shifting disease management strategies toward increased dependence on biological and cultural controls and decreased pesticide importance. For example, the public perceives that residues of synthetic chemical pesticides create food safety problems and that chemicals are inherently deleterious to the environment. This perception has caused major changes in pesticide use in the food production and processing industries and has resulted in government-mandated reductions of pesticide use in several countries. Concomitantly, the number of registered pesticides, particularly for minor crops, is decreasing. Minor crops now include most fruits, vegetables, and nuts, all of which depend greatly on pesticides to maintain quality and productivity.

The loss of registered pesticides is due not only to the loss of registrations of older materials but also to the astronomical costs of discovering and registering a new pesticide. These costs cannot be recovered on minor crops. Resistance to pesticides is an additional and ever-increasing problem, as is ground and surface water quality. Public concerns regarding endangered species, farm worker safety, and pesticide drift in heavily populated areas are increasingly restricting the uses of many pesticides. Finally, more producers are beginning to use nonpesticide controls so they can compete in the organic foods market. Our task is to address the sustainability, competitiveness, food security, and reliability of the evolving system as we change the overall mix of crop protection strategies in IPM.

## Biological Control

The term "biological control" has different meanings. We will use the definition proposed by Baker and Cook (4): "Biological control is the reduction of inoculum or disease-producing activity of a pathogen accomplished by or through one or more organisms other than man." This definition is broad enough to encompass classic approaches to biocontrol that influence pest populations as well as newly emerging biocontrol strategies. These new strategies include the use of plant growth-promoting rhizobacteria (PGPR) seed inoculants, induced resistance, biotic systems that exclude the pathogen from the host, and transgenic plants. Biological control strategies have been limited by a paucity of biocontrol products, poor economics of biocontrol agents, and the cost and volume of soil amendment materials required to favor disease suppression by biological agents (1,25,29).

At this time, only five biocontrol products are registered for use by the U.S. Environmental Protection Agency (EPA) for control of plant diseases (7): BINAB-T, a *Trichoderma*-based mycofungicide for protection of pruning wounds; Galltrol-A, based on *Agrobac-*

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*terium radiobacter* strain K-84, for control of crown gall; Dagger G, based on *Pseudomonas fluorescens*, for control of cotton seedling diseases; F-Stop, a *Trichoderma*-based product for control of damping-off of peas, beans, and corn; and GL-21, a *Gliocladium virens*-based product that will be marketed for control of Pythium and Rhizoctonia root rots on ornamental plants. In addition, Quantum 4000 HB, based on *Bacillus subtilis* strain A-13/GB03, is a seed inoculant for peanuts, beans, and cotton and provides control of Rhizoctonia root rot (33). This small number of products is not surprising, since biological control research oriented toward product development has been pursued in the United States for a relatively short time (15–20 yr). For comparative purposes, modern synthetic fungicides have been under development since the 1930s. In addition, the estimated funding for biological control development is a small fraction of that expended for the development of synthetic chemical pesticides. Besides the vast disparity in funding, only corporate entities have the infrastructure necessary to develop national and international patents and saleable formulations and to possess the required expertise in regulatory affairs. Corporations also have the marketing expertise to foster product acceptance by the farmer. Thus, many novel ideas from public sector research have not found their way to the marketplace. If biological control products are to be successfully brought to the marketplace, commercial and public sectors must combine their expertise.

One of the limiting factors in the development of biological control products has been their reliability, efficacy, and spectrum of activity when compared with synthetic chemical pesticides. Biological control products identified to date control a relatively narrow spectrum of diseases on specific crop hosts, are affected by environmental factors (both before and after application), and are often less efficacious than chemical pesticides. One important difference between known biological agents and synthetic chemicals is that biologicals are almost always protectants, while many modern fungicides are systemic and also may be used after infection has occurred. Pest resistance has not been reported for biocontrol products, except in Galltrol-A for control of crown gall (24). However, this may reflect the rather limited deployment of biocontrol products in plant pathology rather than an inherent low potential for development of resistance to biocontrol products.

Biocontrol organisms often continue to produce their active ingredients using their active biosynthetic pathways, whereas synthetic chemicals are constantly degraded by chemical and biological means. Some products also address long-term root health, an area that is beyond the scope of most modern fungicides. Highly efficacious fungicides such as metalaxyl (Ridomil) have a narrow spectrum of activity limited largely to oomycetes and might benefit from combinations with a biological control partner. Combinations of two or more biocontrol agents in a single product could broaden activity and host range. The development of highly efficacious integrated management practices will require utilizing the strengths of biological, cultural, and chemical controls so the weaknesses in one are compensated for by the strengths of the other(s).

Effective use of biological products will require an understanding of plant-microbe ecology and the mechanisms of action of the biological control agents. Biological control agents have both direct action on the pathogen and indirect mechanisms of activity (15). Indirect mechanisms involve alterations in plant physiology. Some of these indirect mechanisms include: the production of plant growth hormones that speed plant or root growth (11,17), improvements in water or nutritional status of the plant because of a more efficient root system, and increased nitrogen fixation because of enhanced *Rhizobium* nodulation (33). These mechanisms can lead to escape from disease or improved tolerance to stress.

Another biocontrol mechanism that is currently being investigated is the induction of systemic disease resistance. Induced disease resistance has been demonstrated for a wide range of host plants and with biological induction agents, including pathogens and nonpathogens (34). In general, induction requires the initial development of necrotic tissues. However, PGPR have recently been shown to induce resistance in cucumber and carnation (36,38), without visible necrosis. The use of PGPR offers the potential for using bacterial inoculants to systemically induce resistance to a wide range of foliar and soilborne plant pathogens, since immunized plants are usually resistant to a diversity of pathogens (34). Cross-protection by mild virus strains or by nonpathogenic *Fusarium oxysporum* can be considered a form of induced resistance (18,34). However, competition in the rhizosphere for infection sites has been shown to be involved in biological strain control of Fusarium wilt of cucumber by a nonpathogenic *F. oxysporum* (18).

Direct mechanisms of biological control involve antibiosis, competition for nutrients or niches, and parasitism or predation. Antibiosis is perhaps the most investigated mechanism, since it suggests a direct method for screening candidates for activity. However, it was not until 1988 that Thomashow and Weller (31) first proved that an antibiotic was involved in disease suppression when they elucidated the mechanisms in take-all control in wheat by *P. fluorescens* strain 2-79. Later, agrocin A production by *A. radiobacter* strain K-84 was proved to be responsible for a portion of the biocontrol of crown gall (24). More recently, production of oomycin A by *P. fluorescens* strain Hv37aR2 was related to control of *Pythium ultimum* on cotton (13). However, many other PGPR are likely to provide disease control in this manner. Production of hydrogen cyanide by *P. fluorescens* strain CHAO (37) also has been implicated in *Thielaviopsis basicola* control of root rot on tobacco.

These are virtually all of the examples where production of antibiotic substances in vitro has been confirmed in vivo. However, selection of biocontrol agents on the basis of in vitro antibiosis is impractical, since only a small percentage of antibiotic-producing strains also have biocontrol activity. The most likely biocontrol organisms must first be ecologically competent in plant-microbe interactions in the soil or on the plant surface. Competition for nutrients or ecological niches is another mechanism whereby biocontrol agents reduce plant disease. Production of siderophores by pseudomonad PGPR and competition for ferric iron are classic examples of competition for a limited nutrient needed by plant pathogens (5). While only hypothesized, it seems logical that fast-growing PGPR would effectively compete with slower growing pathogens for nutrients available in root exudates or sloughed cells in the rhizosphere. This mechanism was proposed by Elad and Chet (10) for control of *Pythium aphanidermatum* on a range of plants. In this case, competition was between germinating oospores and PGPR.

Another interesting competition is for infection sites or ecological niches. The competition for infection sites by *A. radiobacter* K-84 is partially responsible for reduced infection by *A. tumefaciens* (24). Another example of biological control by competition for infection site is a report of *Pseudomonas* sp. competing for niches with *Pythium ultimum* on sugar beet seeds and seedlings (19).

Improved plant growth and performance due to suppression of pathogenic but nonparasitic rhizobacteria by PGPR is another example of competition. It is hypothesized that these deleterious rhizobacteria (DRB) damage plants by producing hydrogen cyanide or other products that are deleterious to plant growth. In one mechanism, PGPR compete in the rhizosphere with DRB, decreasing their hydrogen cyanide production by siderophore-mediated competition for ferric iron (2,6).

Parasitism and predation are common mechanisms for fungal biological control agents such as *Trichoderma* sp., *Gliocladium virens, Laetisaria arvalis, Coniothyrium miniforms, Pythium nunn,* *Talaromyces flavus*, and *Sporidesmium sclerotivorum* (1). Like other previously discussed biological control agents, *Trichoderma* and *Gliocladium* have more than one mechanism of action. These fungi also produce antibiotic substances that are partially responsible for their activity (8). Parasitism and predation also can be important factors in the biological control of nematodes (2,3). Biological control agents that suppress plant-parasitic nematodes include fungi, bacteria, and some invertebrates (nematodes, mites, earthworms, arthropods, protozoans, and tardigrades). Additionally, collembolans have been shown to be predators of soil-inhabiting fungi such as *Rhizoctonia solani, Sclerotium rolfsii, Macrophomina phaseolina, Verticillium dahliae*, and *F. o.* f. sp. *vasinfectum* (8). At this time, no biological control agent has been marketed for nematode control; however, soil amendments that increase biological suppressiveness have been identified (25). One commercial amendment, Clandosan 618 (IGENE Corporation, Columbia, MD), provides nematode control both by releasing ammonia from urea and chitin in the formulation and by buildup of chitinolytic microorganisms that degrade chitin in nematode egg shells. Initial phytotoxicity ($NH_4$-induced) and application volume are major constraints to the use of this and other amendment-type products (26).

The understanding of these mechanisms for biological control may lead to the development of new classes of products and should assist in creating combinations of active organisms, pesticides, or cultural controls that will improve the reliability and efficacy of disease control. Knowledge of mechanisms will help in the identification of improved biological control agents by allowing industry and university researchers to appropriately select superior organisms from the large number of potential biological control agents available.

It is important to understand that many potential biocontrol agents have been identified and that often their mode of action has been elucidated, but they still have failed to provide acceptable control. In many cases this occurs because we do not understand their ecological requirements for survival, colonization, and/or biological control activity. Rhizosphere and phyllosphere competence are particularly important considerations for biological control of plant diseases (3,30). The lack of success with foliar biocontrol agents is primarily due to lack of understanding of the phyllosphere ecosystem (3). However, a novel food-base concept for support of foliar biocontrol organisms has been reported that feeds and protects biocontrol agents on the phyllosphere and controls peanut leaf spot, early blight of potato and tomato, Septoria leaf spot, bacterial speck and bacterial spot of tomato, and sooty blotch and flyspeck of apple. Both fungal and bacterial antagonists were used in conjunction with insoluble formulations of biopolymers that served as a food source and provided physical protection (9,16,21,22).

## Development of Products

The integration of biological controls into IPM systems will require the availability of products for farm use. Biocontrol products must meet the same development requirements as commercial pesticides. First, the demand for the product and market size must justify investment in research, development, regulatory compliance, and marketing. To date, most biological controls have had a relatively narrow spectrum of efficacy. It is difficult to economically justify development for a single pathogen on a single crop or where ecological considerations limit performance. However, development costs of biologicals may prove to be much lower than the \$20–\$40 million now commonly associated with development of a synthetic chemical pesticide. Combinations of biological control agents with different spectrums of disease control efficacy, environmental tolerance (pH, temperature, host genotype, etc.), or combinations of biological, chemical, or cultural controls may eventually be developed that will allow broad crop adaptation as well as multiple pathogen suppression and be cost-effective from both a development and a farm benefit standpoint.

Efficacy of future biocontrol products must be high and consistent. Biological control products or agents have not had the high degree of consistent, reliable performance commonly demanded of pesticides. This performance standard can only be achieved when greater levels of funding and greater scientific understanding of mode of action and ecology are integrated into biological control product development. Until this occurs, biologicals will be limited to niche markets where no effective chemicals are registered, where growers desire no synthetic chemical inputs (e.g., organic farmers), or where high-value crops are grown under controlled conditions. High levels of quality control in fermentation or culture and formulation will be required so that efficacy is maintained from manufacturing through field application.

Biological control products also must meet acceptable standards for environmental and toxicological safety. Biological agents used in control of plant diseases are primarily microbial agents. Because they are used for pest control they are regulated as pesticides by the EPA and must satisfy environment and test protocols similar to synthetic pesticides. In addition, biological agents must satisfy USDA-APHIS (Animal and Plant Health Inspection Service) criteria for interstate movement and release into the environment because they are considered to be genetically novel or exotic organisms. These two regulatory agencies pose a serious constraint to the timely development and marketing of biological control products. These agencies should develop a different set of criteria for biological products. These new criteria should address whether a biological agent could be a potential pest, as well as whether people handling the product or consuming treated foods will be at risk. Even though many microbial agents produce antibiotic and other biologically active compounds, the amounts are very small and in specific sites. Additionally, the active molecules may be at low concentration in the formulation and should biodegrade rapidly in the environment, since they are of biological origin. Therefore, while the antibiotics or other products may have some undesirable toxicological characteristics, they should be less hazardous than synthetic chemicals because they are not concentrated either in the formulation or on the plant. Thus their risk quotient should be much lower.

The biological control product also must have acceptable shelf life without special storage requirements. Because biological control products are living organisms, products must be formulated so their viability is maintained. Two basic strategies can be employed. One is to select organisms that form dormant structures highly tolerant of environments likely to occur in storage, shipment, and field applications. The second strategy is to utilize formulations and packaging that allow for viability in these environments.

Manufacture of the biocontrol product also must be cost-effective and provide consistent product quality. The experience of the pharmaceutical industry may be critical in developing efficient fermentation practices for microbial biocontrol agents. However, these operations will probably have to be less expensive, since the price of the final product will reflect growth of large volumes of organisms rather than refined products as used by the pharmaceutical industry. Quality control must address all factors that deliver a viable biocontrol agent to the field. In addition, research must elucidate mechanisms of action, ecological (rhizosphere, phyllosphere) competence, formulation, etc., in order to assure an efficacious product. Further, public and industry scientists must develop criteria that accurately predict when a crop response can be expected and also when none will occur, thus preventing use in nonresponsive locations. Such a predictive method for use of *B. subtilis* PGPR on peanuts has been developed (33).

Application of the biocontrol product also should be possible with existing equipment. Because farmers will not want to invest in specialized biocontrol application equipment, products that utilize standard equipment and application techniques are more likely to be adopted by users.

Biocontrol products also must be compatible with cultural and chemical controls when used in IPM programs. As previously discussed, biological control agents may have a narrow spectrum of disease control and also a lower degree of efficacy than chemical pesticides. Therefore, biological control agents and pesticides will likely be applied together, so that the combination can provide benefits not possessed by either component alone. An interesting concept might be to utilize biological agents and reduced rates of pesticides to achieve a high degree of reliability and efficacy. Additionally, genetic engineering of organisms to expand their spectrum of action or host competency is possible. However the existing regulatory environment makes this a more distant prospect. Lastly, biological control agents must be compatible with control practices for other pests and with cultural practices used in crop production.

## Cultural Controls

Parry (20) defines cultural controls as encompassing "all aspects of crops husbandry which influence disease development, including resistant varieties and biological control." Cultural controls include regulatory measures such as quarantines, crop-free periods, certification, crop rotations, tillage, santitation, eradication of alternate hosts, selection of favorable conditions for planting, management of the environment, selection of resistant cultivars, nutrient management, and management of the farming or culture system. Cultural controls are the chief means of management in traditional farming systems (32). Examples of cultural controls (in addition to and elucidation of those mentioned above) used by both traditional and modern farmers to reduce the probability of losses from plant diseases are: adjusting crop density and depth and time of planting; altering soil fertility, plant architecture, soil drainage, and soil pH; burning; eradicating alternative hosts and volunteers; fallowing; flooding; using high-vigor seed; irrigating; using light-selective greenhouse coverings; manipulating shade; modifying postharvest environment; mulching; using multistory or multiple cropping, non-"dirting" cultivation, organic soil amendments, and pathogen-free planting material; planting diverse crops; planting in raised beds; using reflective mulches; rotating crops; using row orientation; selecting sites; cropping sequentially; solarizing soil; planting trap crops or toxic crops; controlling weeds; and harvesting expeditiously. While these controls are relatively efficacious, they may require highly diverse farming systems and often high labor input. Some are not adaptable to the economic, regulatory, and farm program environment of today's commercial agriculture.

The efficacy of cultural controls is well documented, and they are integral to most successful cropping systems. Cultural controls are the primary control measures employed by proponents of alternative agriculture. While specific cultural control measures may be highly effective in one cropping system, they may not be sufficiently efficacious or adaptable to be broadly applied by all commercial agriculturalists. Nonetheless, cultural controls collectively provide a resilient skeleton for crop protection in many cropping systems and serve to reduce problems that require intervention with pesticides or alternatives.

Understanding pathogen biology and epidemiology can provide convincing arguments for adopting different cultural practices. Cultural controls that reduce primary inoculum or reduce infection frequency are often highly effective and adaptable, even in polycyclic diseases. For example, the use of a flail mower in winter to debark prunings in apple orchards has reduced dependency on fungicides for control of black rot in Georgia apple orchards (28).

In tropical to subtropical environments, soil solarization is a practical method for controlling soilborne pathogens, particularly where plastic mulches are utilized to promote crop growth and control weeds (14). The use of reflective mulches to reduce insect-vectored viruses is an example of cultural management of vector behavior (12). Another interesting use of plastic films is as greenhouse coverings to reduce plant disease by selectively altering light transmission spectra (35).

## Combined Use of Biological and Cultural Controls

Use of cultural controls in combination with biological controls can offer efficacy nearly equal to that of pesticide-based systems. Recent research at Auburn University compared use of plastic row mulches in combination with a food-based foliar biofungicide to the fungicide chlorothalonil for control of tomato leaf diseases (23); the mulch and biofungicide provided early blight control equal to that provided by weekly sprays of chlorothalonil on tomatoes grown in bare soil.

Cultural practices such as rotation and tolerant cultivars that are not sufficiently efficacious alone can be combined with other controls (e.g., biological agents, reduced rates of pesticides, less effective pesticides, etc.) to create highly efficacious control systems that allow for reduced inputs. However, development of and support for such a system will require a higher level of technological support than is presently supplied by most public sector extension programs. Such systems can only be implemented with a high level of research technology transfer support and when growers understand the risks associated with such integrated systems.

The integration of biological, cultural, and chemical controls into crop protection strategies for modern agricultural systems will occur because the previously mentioned factors are forcing disease management strategies to change. The degree of integration will depend on economics, crop type, farm size and location, government programs and their restrictions, the availability of reliable biocontrol and pesticide products, the grower's perception of risk, and the requirements of the marketplace. Biological and cultural controls will play an increasing role in crop protection strategies, but with only a few biocontrol products available and with economic and regulatory constraints existing for many cultural control systems, it is obvious that pesticides will be required to maintain quality and competitiveness in our food production system for some time to come.

## LITERATURE CITED

1. Adams, P. B. 1990. The potential of mycoparasites for biological control of plant diseases. Annu. Rev. Phytopathol. 28:59-72.
2. Alström, S., and Burns, R. G. 1989. Cyanide production by rhizobacteria as a possible mechanism of plant growth inhibition. Biol. Fertil. Soils 7:232-238.
3. Andrews, J. H. 1990. Biological control in the phyllosphere: Realistic goal or false hope. Can. J. Plant Pathol. 12:300-307.
4. Baker, K. F., and Cook, R. J. 1974. Biological Control of Plant Pathogens. W. H. Freeman & Co., San Francisco.
5. Bakker, P. A. H. M., van Peer, R., and Schippers, B. 1990. Specificity of siderophore receptors and biocontrol by *Pseudomonas* sp. Pages 131-142 in: Biological Control of Soilborne Plant Pathogens. D. Hornby, ed. CAB International, Wellingford, England.
6. Bakker, A. W., Bakker, P. A. H. M., and Schippers, B. 1989. Cyanide-producing rhizosphere pseudomonads: A factor limiting potato root growth and tuber yield in high frequency potato-cropping soil? Pages 153-162 in: Effects of Crop Rotations on Potato Production in Temperate Zones. J. Vos, C. D. van Loon, and C. J. Bollen, eds. Kluwer Academic Publications, Dardrech, Netherlands.
7. Cook, R. J. 1991. Biological Control of Plant Diseases: Broad Concepts and Applications. Pages 1-29 in: The Biological Control of Plant Disease. Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei, Taiwan.
8. Curl, E. A., and Harper, J. D. 1990. Fauna-microflora interactions. Pages 369-385 in: The Rhizosphere. J. M. Lynch, ed. John Wiley & Sons, New York.
9. Davis, R. F., Backman, P. A., Rodríguez-Kábana, R., and Kokalis-Burelle, N. 1991. Biological control of apple fruit diseases by *Chaetomium globosum* formulations containing a carbon source. (Abstr.) Phytopathology 81:1152.

10. Elad, Y., and Chet, I. 1987. Possible role of competition for nutrients in biocontrol of Pythium damping-off by bacteria. Phytopathology 77:190-195.
11. Frommel, M. I., Nowak, J., and Lazarovits, G. 1991. Growth enhancement and development modifications of *in vitro* grown potatoes (*Solanum tuberosum* ssp. *tuberosum*) as affected by a nonfluorescent *Pseudomonas* sp. Plant Physiol.96:928-936.
12. Greenough, D. R., Black, L. L., and Bond, W. P. 1990. Aluminum-surfaced mulch: An approach to the control of tomato spotted wilt virus in solanaceous crops. Plant Dis. 74:805-808.
13. Howie, W. J., and Suslow, T. V. 1991. Role of antibiotic biosynthesis in the inhibition of *Pythium ultimum* in the cotton spermosphere and rhizosphere. Mol. Plant Microbe Interact. 4:393-399.
14. Katan, J., and DeVay, J. E., eds. 1991. Soil Solarization. CRC Press, Boca Raton, FL.
15. Kloepper, J. W. 1991. Plant growth-promoting rhizobacteria as biological control agents of soilborne diseases. Pages 142-152 in: The Biological Control of Plant Disease. Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei, Taiwan.
16. Kokalis-Burelle, N., Backman, P. A., Rodríguez-Kábana, R., and Ploper, L. D. 1991. Chitin as a foliar amendment to modify microbial ecology and control disease. (Abstr.) Phytopathology 81:1152.
17. Lifshitz, R., Kloepper, J. W., Kozlowski, M., Simmon, C., Carlson, S., Tipping, E. M., and Zaleska, I. 1987. Growth promotion of canola (rapeseed) seedling by a strain of *Pseudomonas putida* under gnotobiotic conditions. Can. J. Microbiol. 33:390-395.
18. Mandeel, Q., and Baker, R. 1991. Mechanisms involved in biological control of Fusarium wilt of cucumber with strains of nonpathogenic *Fusarium oxysporum*. Phytopathology 81:462-469.
19. Osburn, R. M., Schroth, M. N., Hancock, J. G., and Hendson, M. 1989. Dynamics of sugar beet seed colonization by *Pythium ultimum* and *Pseudomonas* species: Effects on seed rot and damping-off. Phytopathology 79:709-716.
20. Parry, D. W. 1990. Plant Pathology in Agriculture. Cambridge University Press, Cambridge, England.
21. Ploper, L. D., and Backman, P. A. 1991. Modification of leaf microflora by foliar amendments and effects on diseases of tomato, potato, and apple. (Abstr.) Phytopathology 81:1152.
22. Ploper, L. D., Backman, P. A., Cunningham, S. D., and Martin, M. J. 1991. Effects of chitin amendments and added chitinolytic microorganisms on foliar diseases of tomato. (Abstr.) Phytopathology 81:1153.
23. Ploper, L. D., Backman, P. A., Stevens, C., Khan, V. A., and Rodríguez-Kábana, R. 1992. Effects of soil mulch, row cover, and biological and chemical foliar treatments on early blight of tomato, 1991. Biol. Cult. Tests 7:38.
24. Ryder, M. H., and Jones, D. A. 1990. Biological control of crown gall. Pages 45-63 in: Biological Control of Soilborne Plant Pathogens. D. Hornby, ed. CAB International, Wellingford, England.
25. Rodríguez-Kábana, R. 1986. Organic and inorganic amendments to soil as nematode suppressants. J. Nematol. 18:129-135.
26. Rodríguez-Kábana, R., Boube, D., and Young, R. W. 1990. Chitinous materials from blue crab for control of root-knot nematodes. II. Effect of soybean meal. Nematropica 20:153-168.
27. Sayre, R. M., and Walter, D. E. 1991. Factors affecting the efficacy of natural enemies of nematodes. Annu. Rev. Phytopathol. 29:149-166.
28. Starkey, T. E., and Hendrix, F. F., Jr. 1980. Reduction of substrate colonization by *Botryosphaeria obtusa*. Plant Dis. 64:292-294.
29. Sun, S.-K., and Huang, J.-W. 1985. Formulated soil amendment for controlling Fusarium wilt and other soilborne diseases. Plant Dis. 69:917-920.
30. Taylor, A. G., and Harman, G. E. 1990. Concepts and technologies of selected seed treatments. Annu. Rev. Phytopathol. 28:321-339.
31. Thomashow, L. S., and Weller, D. M. 1988. Role of a phenazine antibiotic from *Pseudomonas fluorescens* in biological control of *Gaeumannomyces graminis* var. *tritici*. J. Bacteriol. 170:3499-3508.
32. Thurston, H. D. 1990. Plant disease management practices of traditional farmers. Plant Dis. 74:96-102.
33. Turner, J. T., and Backman, P. A. 1991. Factors relating to peanut yield increases after seed treatment with *Bacillus subtilis*. Plant Dis. 75:347-353.
34. Tuzun, S., and Ku, J. 1991. Plant immunization: An alternative to pesticides for control of plant diseases in the greenhouse and field. Pages 30-40 in: The Biological Control of Plant Disease. Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei, Taiwan.
35. Vakalounakis, D. J. 1992. Control of fungal diseases of greenhouse tomato under long-wave infrared-absorbing plastic film. Plant Dis. 76:43-46.
36. van Peer, R., Niemann, G. J., and Schippers, B. 1991. Induced resistance and phytoalexin accumulation in biological control of Fusarium wilt of carnation by *Pseudomonas* sp. strain WCS417r. Phytopathology 81:728-734.
37. Voisard, C., Keel, C., Haas, D., and Défago, G. 1989. Cyanide production by *Pseudomonas fluorescens* helps suppress black root rot of tobacco under gnotobiotic conditions. EMBO J. 8:351-358.
38. Wei, G., Kloepper, J. W., and Tuzun, S. 1991. Induction of systemic resistance of cucumber to *Colletotrichum orbiculare* by select strains of plant growth-promoting rhizobacteria. Phytopathology 81:1508-1512.